Atmospheric Optical Propagation

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Award Number: N0001407WR20198
http://sunspot.spawar.navy.mil

LONG-TERM GOALS

This project provides a description of the propagation of optical (visible and infrared) waves in the marine atmospheric surface layer by developing and testing a comprehensive optical propagation assessment model suite. The project combines model development and field experimentation with a particular emphasis on coastal environments.

OBJECTIVES

1) The development of an accurate determination of optical extinction in the coastal marine environment. A reliable aerosol model is a necessity, and work this year has modified the Advanced Navy Aerosol Model (ANAM) to address all of the weakest elements of the current version of ANAM.

2) EOSTAR has been developed to provide the results of applied research to 6.4 applications, such as tactical decision aids. The EOSTAR project is an end-to-end model development for infrared and visible absorption, scattering, refraction, and scintillation using local meteorological input data. A particular focus for the modification process is the submarine periscope detection problem. Work this year has concentrated on development of an accurate representation of a periscope and background.

3) Optical turbulence can be just as important for beam degradation as extinction (and often more important), so an improvement in model performance is needed. Work this year tested experimental field results showing the effects of near-surface turbulence on a propagating optical beam. The technical objective is an improvement of the prediction and use of the refractive index structure parameter C_n^2 and the proper use of this quantity to accurately model all turbulence-related beam degradation within the littoral marine atmosphere.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 2007	**Annual**	**00-00-2007 to 00-00-2007**

4. TITLE AND SUBTITLE
Atmospheric Optical Propagation

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
SPAWARSYSCEN San Diego code 5548,49170 Propagation Path,San Diego,CA,92152

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT
This project provides a description of the propagation of optical (visible and infrared) waves in the marine atmospheric surface layer by developing and testing a comprehensive optical propagation assessment model suite. The project combines model development and field experimentation with a particular emphasis on coastal environments.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

APPROACH

The central organizing emphasis for the optical propagation task is the creation of a model suite which will accurately predict propagation in the marine near-surface atmosphere from source to sensor, or from source to target. Our work focuses on the two primary atmospheric sources of signal or beam degradation: extinction by gases and aerosols, and optical turbulence. Both of these phenomena are complex and difficult to model, and a successful description requires an interplay between field experiments and analysis.

We developed a large dataset from a long-term experimental field test for two infrared wavelengths propagated over a 7.07 kilometer path at Zuniga Shoal. The goal is to measure the transmission of near-IR wavelengths (1.06 and 1.62 micron) in a marine atmospheric surface layer. The propagation range at Zuniga Shoal has been used previously, in the EOPACE series of tests. However, this was the first test for the near-IR wavelengths that are the primary choice for the development of the Navy High Energy Laser (HEL) weapons system.

Dr. Lex van Eijk (TNO Defence, Security and Safety, Netherlands) directs the ANAM analysis and upgrade. The Zuniga Shoal 2005-2006 data-set has proved to be a fertile test-bed for a thorough review of the strengths and weaknesses of the ANAM. Dr. van Eijk's critique and re-design of the ANAM model has required a review of all of the weakest elements of the model, and each of the 4 component modes of the ANAM 4 model is currently under review. Mode amplitudes, mode diameters, and the shape and definition of the basic component modes in ANAM are being changed to better reflect the underlying physics (instead of computational convenience). The two production modes are now grouped into one consensus sea-spray source function.

EOSTAR (=**E**lectro-**O**ptical **S**ignal **T**ransmission **A**nd **R**anging) is a flexible simulation tool to assess the performance of optical & infrared systems in the near-surface marine atmosphere. All of the first-order beam degradation factors such as extinction, turbulence, and mirages are calculated, and the results are available as a synthetic camera image. This complete array of modules enables the simulation of a propagation path in any sort of environmental condition.

Dr. Dimitri Tsintikidis (SSC San Diego) is directing the work to advance the EOSTAR capabilities to enable periscope detection against maritime backgrounds. The propagation features in EOSTAR are well-developed and tested; the emphasis in our current program is the development of models for detection of a submarine periscope. This process has required the development of a high-fidelity thermal signature model for two representative periscope masts.

We have also initiated the development of wake signature models for several periscope speeds. Due to interest in wavebands in the visible and near-IR, it is important to carefully model reflectance as well as emissivity features of the sea surface. It is also critical to make these multi-spectral calculations of reflectance and emissivity for foam and bubbles in the near-wake.

NSLOT: The upgrade of the optical turbulence model is founded upon the comprehensive analysis of field test data collected over a one-year period at Zuniga Shoal. The Zuniga Shoal 2005-2006 test spanned CY 2005 and concluded in December 2006, producing over 110 measurement days of data.

Dr. Steve Hammel is leading the effort to test optical turbulence models and to select the most useful analytical approach to predict the effects of turbulence on laser beam degradation. Almost all of the data includes high quality meteorological measurements from a mid-propagation path buoy, and a direct measurement of turbulence from the buoy platform. In our analysis we are therefore able to make a detailed comparison of optical turbulence determined five different ways: direct turbulence data from the 3-dimensional sonic anemometer, scintillometer data from the 7.07 km path at 1.06 µm and 1.62 µm (SSC scintillometer), BLS2000 data at 880 nm, the YAG 1.064 µm laser beam profile, and the output of the NSLOT model driven by the buoy-based meteorological data.

WORK COMPLETED

Extensive field test data have been analyzed for the 7.07 km Zuniga Shoal propagation test site. The resulting application to model tuning and upgrades are discussed below.

ANAM Upgrade: The aerosol model analysis and upgrade effort for ANAM has been both radical and broad. Nearly every core parameter is subject to examination and revision, and possible elimination. The core functional elements of the model have been removed or revised: the log-normal function is now replaced by a physics-based mode which is the aerosol community consensus sea-spray source function. Tuning has commenced for this function to accurately determine the parametric dependence of the new source function. The tuning process is also utilizing results from the SeaCluse model to develop vertical dispersion and particle gradient estimates.

Another major modification is the replacement of the Gerber function (which injects the humidity dependence into the model) by a new wetting algorithm. This will generate a significant alteration in predicted extinction increase as a function of relative humidity. The humidity dependence is currently being analyzed for other possible modeling approaches, including external mixture models.

The Air Mass Parameter (AMP) has long been reviled as an impossible parameter to determine a priori. The AMP has been removed, and our completed study of fetch statistics shows that Ångstrom coefficient should be a useful discriminator for continental vs. maritime aerosol. This approach will be a foundational element of the ANAM improvement.

NSLOT Upgrade: The initial effort has concentrated on the accurate formulation of the dimensionless structure parameter functions (f_T, f_q & f_{Tq}) which describe temperature and humidity fluctuations as a function of stability. A new dimensionless temperature structure function parameter was defined based upon the Zuniga Shoal long-term test. Because of data limitations, this new definition of f_T could be determined only for unstable conditions, but a test of the model versus field data indicates improved agreement between the bulk determination and the direct (sonic) measurement of C_n^2.

The final test period of the Navy Zuniga Shoal Propagation Test occurred in November-December 2006. This final intensive operational period was the first test to include a laser link sharing the same propagation path as all other optical measurements. The laser test, conducted by personnel from the Naval Air Warfare Center in China Lake CA, produced high fidelity intensity imagery of the propagated YAG 1.064 µm laser beam. We developed algorithms to deduce C_n^2 from the measured laser beam wander (see fig. 1).

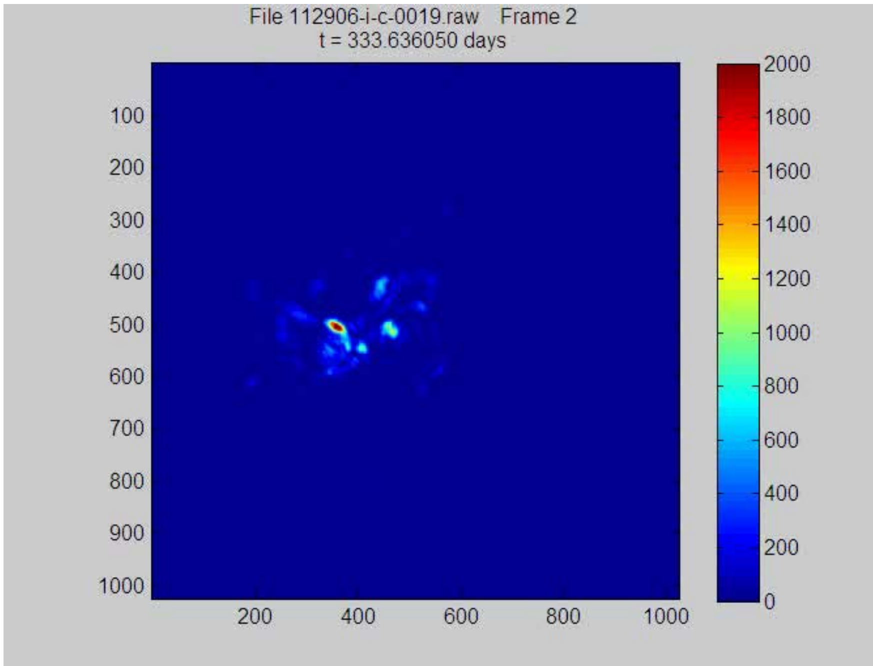

Figure 1: Image of laser beam (1.064 µm) captured in a 56 cm aperture receiver telescope at Zuniga Shoal. In subsequent frames the beam wanders over the aperture due to atmospheric turbulence effects.

The current NSLOT model uses a temperature structure parameter function determined from a single over-water experiment (Edson 1998), but only for unstable conditions. This function does not include possible wave-influences and does not include stable conditions. Model modifications are based upon a correlation of the surface roughness specifications for momentum, heat and moisture transfer. We identified a previously unreported 'bump' in the dimensionless structure parameter functions f_T for low-wind, weakly stable conditions. It is possible that this feature will provide a clue for the appropriate parameter adjustment in the NSLOT model. In Figure 2, stability is directly related to the air-sea temperature difference $T_{air} - T_{sea}$, with positive values corresponding to stable conditions, and negative values corresponding to unstable conditions. Three different wind speed regimes are displayed, with the lowest wind speed regime for $< 0.5w < 2.5\,\mathrm{ms}^{-1}$ shown in red. Note the prominent 'bump' for $0 < T_{air} - T_{sea} < 1.5$. We have found this behavior for other experimental field datasets as well. The robust nature of this feature in several different data collections is a compelling indication that an in-depth analysis will reveal important model characteristics that require modification.

EOSTAR upgrade: A field test was conducted at the Naval Undersea Warfare Center (NUWC), Newport RI. The thermal signature of a stationary Type 18 periscope in diverse meteorological conditions was measured in both the mid-wave and long-wave bands utilizing our upgraded AGEMA radiometric camera. Comparison between the AGEMA imagery and the Multi-Service Electro-optic Signature (MuSES) model, developed by ThermoAnalytics Inc., proved that MuSES reproduces well the Type 18 thermal behavior in both wavebands. Furthermore, several MuSES scenarios for different periscope speeds were inserted into TAWS (Target Acquisition Weapons Software), giving TAWS a periscope detection capability.

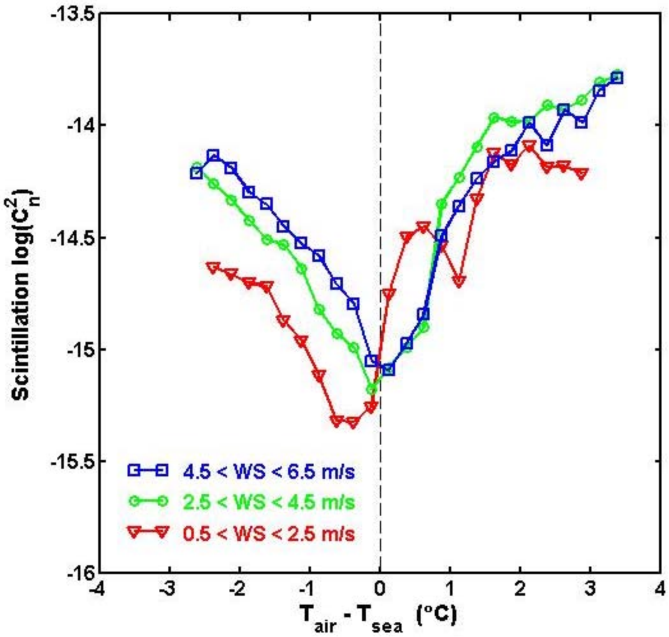

Figure 2: C_n^2 is binned according to values of T_{air}-T_{sea}. By separating the values into low, medium, and higher wind speed sets, the appearance of a pronounced 'bump' appears for the low wind speed case.

RESULTS

ANAM in a littoral environment requires a new functional dependence on local relative humidity. We have learned that there are several important parameters that should be exploited in the new ANAM. First, the Ångstrom coefficient appears to be a very promising discriminant for distinguishing continental from marine aerosols. We will continue to test the determination of Ångstrom coefficients by means of sun photometer measurements to eliminate the Air Mass Parameter dependence of ANAM. Second, humidity as an input parameter was not utilized correctly in the current ANAM, and our tests of external mixture models using a separate humidity-driven predictor have produced favorable results. This has resulted in a re-design of ANAM that should be called revolutionary rather than evolutionary, since so much of ANAM 4.0 has been changed or replaced.

NSLOT: Both models and incoherent scintillometers suffice to characterize turbulence effects on laser propagation. Analysis of the Zuniga Shoal test reveals that scintillometer measurements and the NSLOT model are generally accurate predictors of laser perforamance in a littoral environment. The final test series at Zuniga Shoal included a 1.064 µm YAG laser propagation test and incoherent scintillometers for environmental characterization, and turbulence effects on the laser were well-predicted using results from the incoherent scintillometer tests. This means that scintillometer measurements and subsequent analysis will be sufficient to deduce many of the important effects of turbulence on coherent propagating beams. The comparison between laser and scintillometer data is shown in figure 3: the large discrepancies when values of C_n^2 exceed 2×10^{-15} are due to the fact that portions of the laser beam are forced outside the image aperture, and this generates a downward bias in the calculation of C_n^2 using laser beam profile imagery.

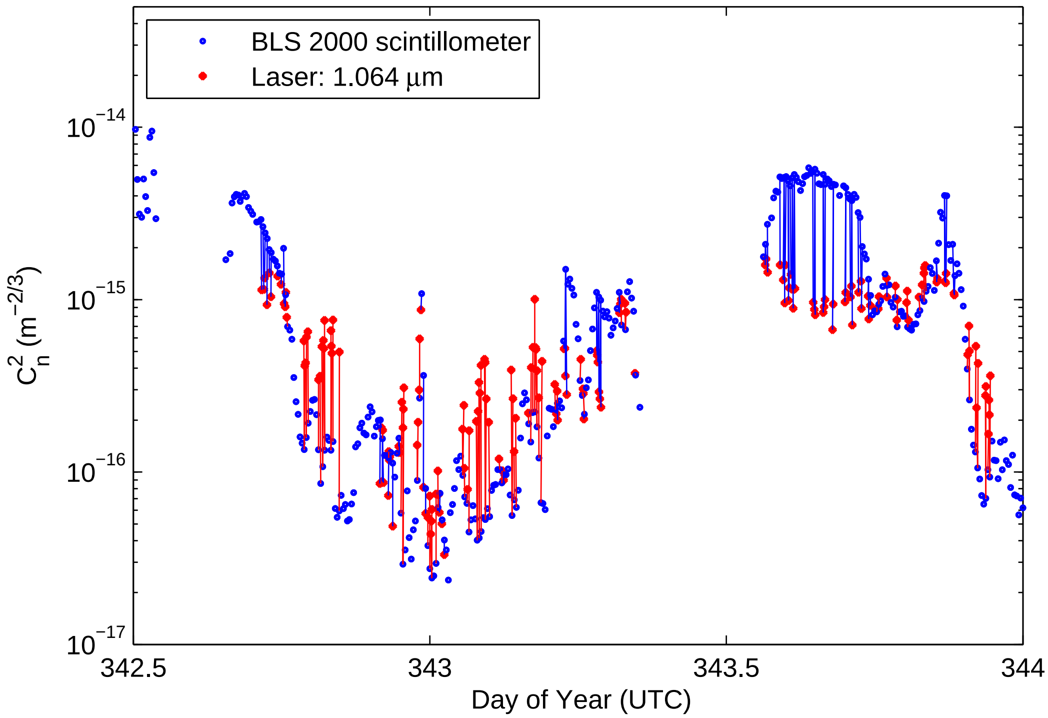

Figure 3: A comparison of scintillometer data and laser data from the Zuniga Shoal experiment

EOSTAR enhancements include more realistic target visualization and designation as well as improved realism for sea and sky backgrounds, which is critical for the development of a counter-detection capability. EOSTAR simulations of turbulent blurring and beam wander have been improved, resulting in a more realistic visualization of thermal ship signatures. Finally, EOSTAR can now be used to generate image simulations for representative periscopes in the near-IR and visible wavebands.

IMPACT/APPLICATIONS

The performance of optical and infrared systems for long-range near-surface maritime applications is usually limited by a stressing propagation environment and not by the system design. By providing a validated model set for environmental assessment, this work will enable an objective and more accurate trade-space for design studies for the Navy proposed High Energy Laser Weapons System.

This effort will also provide a framework for the test and possible integration of optical channels in the Navy communications architecture.

The detection of a submarine periscope is a current project utilizing the EOSTAR tool, and this work is a part of the development of a threat assessment tool for submarines at periscope depth.

RELATED PROJECTS

This work will support, and is supported by, a field experiment to evaluate HEL propagation funded by ONR 351, NAVSEA PMS 405, and PMS 435.

This work supports the development of high-speed optical free-space ship-to-ship and ship-to-shore communications, and the development of communication link assessment efforts supported by ONR 313, including the Communication Link Assessment in Manifold Environment (CLAIME) project.

PUBLICATIONS

1. V. Gadwal, S. Hammel, "*Free Space Optical Communication Links in a Marine Environment*", Proc. SPIE **6304**, 2006 [published].
2. P. A. Frederickson, S. Hammel, D. Tsintikidis, "*Measurements and modeling of optical turbulence in a maritime environment*", Proc. SPIE **6303**, 630307 (2006) [published].
3. D. Tsintikidis, S. Hammel, P. Frederickson, "*Modeling the effects of aerosols on transmission measurements at Zuniga Shoal, California*", Proc. SPIE **6303**, 2006 [published].
4. S. Hammel, D. Tsintikidis, D. Merritt, J. Fontana, "*Atmospheric characterization for high energy laser beam propagation in the maritime environment*", Proc. 8th Ann. Directed Energy Symposium, 2005.
5. J. Kusmierczyk-Michulec, A.M.J. van Eijk, "*Comparison of aerosol size distribution in coastal and oceanic environments*", Proc. SPIE **6303**, 630301 (2006) [published].
6. A. de Jong, A.M.J. van Eijk, M. Moerman, L. Cohen, "*Investigation of aerosol particle size distributions in the San Diego Bay area by means of multi-band transmissometry*", Proc. SPIE **6303**, 63030L (2006) [published].
7. A.M.J. van Eijk, G. Kunz, "*The introduction of horizontal inhomogeneity of meteorological conditions in the EOSTAR propagation model*", Proc. SPIE **6303**, 63030G (2006) [published].
8. A.M.J. van Eijk, D. Merritt, "*Improvements in the Advanced Navy Aerosol Model (ANAM)*", Proc. SPIE **6303**, 63030M (2006) [published].
9. A. de Jong, A. van Eijk, M. Moerman, L Cohen, "*Aerosol size distributions, retrieved from multi-band transmissometer data in the Southern Baltic Sea during the VAMPIRA trials*", Proc. SPIE **6364**, 636406-1 (2006).

AWARDS

1. SPAWAR Systems Center **Department 280 Award (**2007) to Dr. Steve Hammel "For the successful completion of the 2-year Atmospheric Propagation Characterization Experiment" at Zuniga Shoal.